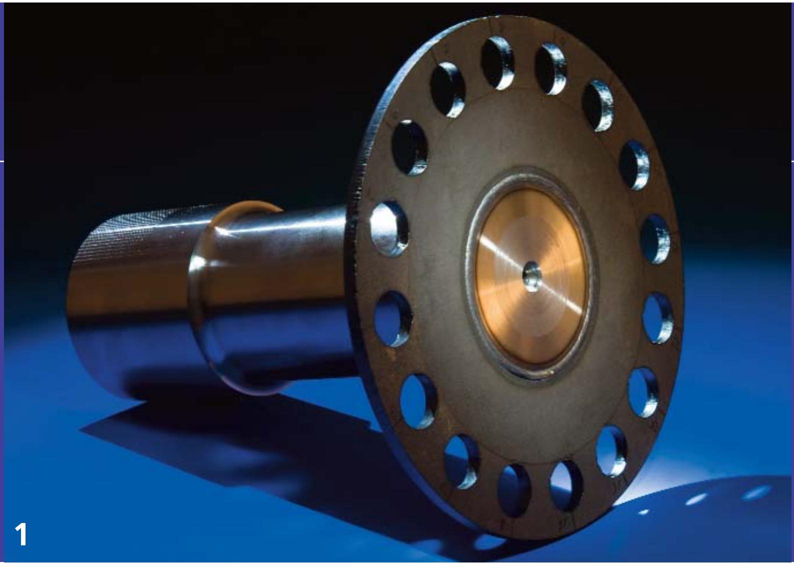


IMPROVEMENT OF THE FATIGUE STRENGTH OF LASER BEAM WELDED PARTS UNDER MULTI-AXIAL LOADING

THE TASK

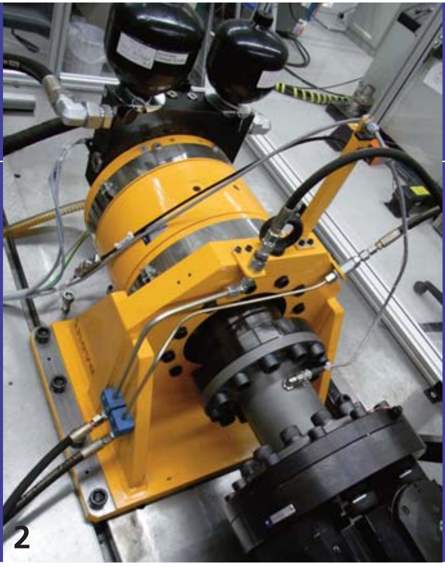
Current strategies to combine lightweight design with modern joining technologies call for detailed knowledge of the mechanical strength of the structural parts to be joined. A typical example is a shaft-hub joint, where the driving force is transmitted through laser beam welded radial or axial circular weld seams. Challenges regarding design as well as process development are manifold. Thus, welding processes must produce reliable and reproducible joints meeting toughness and strength requirements. Appropriate material selection and process optimization by reducing seam lengths and depths are the main parameters to guarantee a resource efficient design. Current design recommendations do not offer solutions to account for cyclic strength under torsional loading for welded structures. Hence, the evaluation is restricted to experimental fatigue results. An experimental evaluation of the cyclic strength of welded prototypes or even whole units of a transmission joint under operation-relevant loading conditions is very time and cost consuming. Hence, strategies have to be developed to evaluate the fatigue strength of the critically loaded welded joints under laboratory conditions. In this respect a simulation of the realistic loading conditions is essential to optimize the welding technology at a very early stage of product design.

OUR SOLUTION

In order to bridge the gap between cost and time consuming prototype testing and laboratory tests of basic homogeneous material samples, a test system was developed and implemented at the Fraunhofer IWS that is capable of combining axial and torsional loading with maximum torque of ± 8 kNm and axial forces up to ± 40 kN at frequencies up to 50 Hz. Superimposing these loads allows for simulating realistic loading conditions as they occur in powertrains. Current research aims to develop a sound basis for the evaluation of the fatigue strength and reliability of welded structures under torsional as well as multi-axial loading conditions. Since an adaptation of laboratory test systems to simulate the exact loading conditions of real parts such as a shaft with a gear is limited, distinctive sample geometries have to be developed to minimize this area of conflict (Fig. 1).

Application oriented test parts are designed to mimic the weld seam geometry, stiffness and heat dissipation conditions of the real structural part at its best. The specimens are then mounted in the testing machine and axial and/or torsional loads are applied in such a way that the multi-axial stress/strain state in the critically loaded weld seam corresponds to that in the real application. Finite element analysis allows to adjust the testing conditions with the true loading conditions in the prototype. Test parameters such as forces, torques, in- or out-of-phase loading and stress ratio are combined in such a way that the load maxima in the specimens correspond to those in the real components.

The test system at IWS (Fig. 2) allows single stage as well as step-load testing with superimposed tensile or compressive mean loads. Hence, in order to reduce time and efforts to evaluate the fatigue strength for a wide range of process parameters of laser beam welded joints, a test design corresponding to the staircase method or the boundary technique can be realized.



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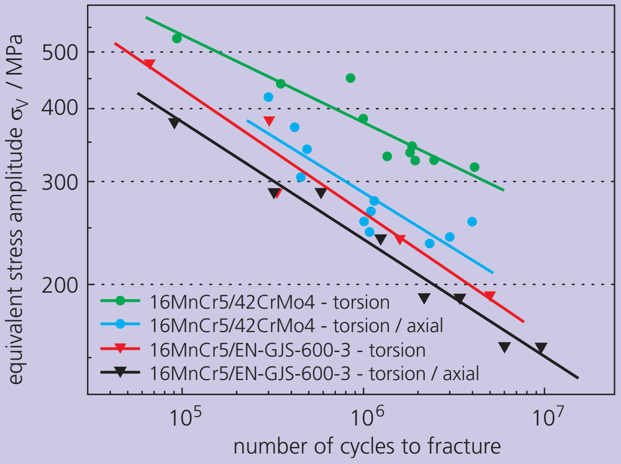
RESULTS

A series of fatigue tests was performed for specimens representing a typical shaft-flange welded joint as shown in Fig. 1. A torque was superimposed by an additional (in-phase) axial force resulting in a combined torsional and bending load in the weld seam allowing an evaluation of the fatigue strength of the shafts base material as well as the welded joint. Two material combinations were tested: heat treatable steel/case hardened steel and cast iron with spherical graphite/case hardened steel. The material combinations were laser beam welded with similar geometries and filler material for the circular weld seams. Fig. 3 depicts the S-N curves obtained in the experiments. The dissimilar welded joint with its poor weldability due to the combination of the cast iron GJS-600-3 with the case hardened steel 16MnCr5 shows remarkably high fatigue strength in the high cycle fatigue regime under pure torsional loads. With 42CrMo4 as shaft material only a minor increase of the fatigue behavior can be achieved. A systematic optimization of the laser beam welding process resulted in similar results comparing the fatigue strength under multi-axial loading conditions - with fatigue strength of the cast iron/case hardened steel combination still meeting the strength specification required. The results presented demonstrate the successful IWS strategy to closely dovetail process optimization with test routines related to realistic loading conditions.

Correlation between equivalent stress amplitude and number of cycles to fracture (S-N-curve for the HCF regime) under torsional and superimposed torsional and axial loading for specimens with circular laser beam weld seams of dissimilar joints (16MnCr5/42CrMo4 and 16MnCr5/EN-GJS-600-3)



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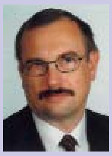
1 *Test part with axial round seam*

2 *Torsional/axial load tester*

CONTACT



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